OPERATIONS ANALYSIS TECHNICAL MEMORANDUM NR 121
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# RAPID ESTIMATION OF RESIDUAL RADIATION DOSAGE

Prepared by

S. R. WOODS

Approved by
Howard J. Talley, Jr.
Acting Chief
Office of Operations Analysis



This memorandum contains the results of an operations analysis study. The findings and conclusions are subject to revision as may be required by new findings or by modification of basic assumptions.

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HEADQUARTERS TACTICAL AIR COMMAND
Langley Air Force Base, Virginia

# ABSTRACT

This memorandum presents a simple and rapid means for estimating the total radiation dose one might expect to receive during exposure in an area contaminated by fission products. Curves are included for exposure periods of 2, 4, 8, 12, and 16 hours and for accumulated doses of 50, 100, and 200 rem. In addition to the curves covering particular exposure periods, a special curve is included for estimating the dose for any period of exposure between 1 and 1,000 hours after detonation. A nomogram is included for converting radiation intensity measured at a particular time after detonation to the reference dose rate at one hour after detonation (H+1). Typical problems and their solutions are given in the body of the memorandum to familiarize the reader with the use of the nomogram and the curves. It must be borne in mind that the nomogram and the curves are based on the simple decay rate equation for normal fission products, $I_t = I_1 t^{-1.2}$, where $I_t$ is intensity in roentgens per hour (r/hr) at "t" hours after burst, and $I_1$ is intensity at one hour after burst (H + 1). Fractionation among fission products and induced activities may cause the decay rate in a particular fallout situation to vary considerably (50% or more) from that of the approximate $t^{-1.2}$ function.

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## 1. INTRODUCTION

For the period between one-half hour to 30 days after surface burst of a nuclear weapon, the following nomogram and curves are considered sufficiently accurate for quick estimates of radiation dosage due to fallout. No consideration has been given to multiple explosions, seeded bombs or neutron-induced ground contamination. However, it is assumed that anyone monitoring fallout build-up downwind from a nuclear explosion will be able to determine an abnormal build-up or decay rate and thereby judge the degree of dependence he might place in his estimate of radiation hazard.

## 2. ASSUMPTIONS

It is reasonable to assume that, in case of nuclear attack on the United States, numerous fallout shelters will be equipped with fixed radiological recording instruments at critical locations outside the shelters from which build-up, peak and decay of radiation intensity can be determined. It is necessary to know, also, the time the nuclear device was detonated in order to make use of the curves.

## 3. EXAMPLES

a. Given a dose rate of 400 r/hr at H+4 hours, find:

(1) Reference dose rate at H+1;

(2) Dose rate at H+10;

(3) Time after burst dose rate will be 50 r/hr.

SOLUTION:

(1) Apply a straight edge to Figure 1 at 400 on the left scale (Measured Dose Rate at H+X Hours) and 4 on the right scale (H+X Hours, Time of Measured Dose Rate). Read 2,100 r/hr at H+1 on middle scale (Reference Dose Rate at H+1 Hours).

(2) Apply the straight edge to Figure 1 at 2100 on the middle scale and 10 on the right scale. Read 130 r/hr on the left scale (Measured Dose Rate at H+X Hours).

(3) Apply straight edge to Figure 1 at 2,100 on the middle scale and 50 on the left scale. Read 22 hours on the right scale (Time of Measured Dose Rate).

b. Given a peaked dose rate of 500 r/hr at a base downwind from a nuclear explosion at three hours after the explosion (H+3) find:

(1) Normalized dose rate (r/hr at H+1);

(2) Dose Rate at H+35 Hours;

(3) Time after burst dose rate will be 15 r/hr.

SOLUTION:

(1) Apply straight edge to Figure 1 at 500 on the left scale and 3 on the right scale. Read 1,900 r/hr at H+1 on the center scale.

(2) Apply straight edge to Figure 1 at 1,900 on center scale and 35 on right scale. Read 25 r/hr on left scale.

(3) Apply straight edge to Figure 1 at 1,900 on center scale and 15 on left scale. Read 54 hours on right scale.

c. Using the 1,900 r/hr reference dose rate found in example "b.1." above, find the earliest time a worker might leave the fallout shelter for a single two-hour work period in the contaminated area so as to receive only:

(1) 50 rem, total dose;

(2) 100 rem, total dose;

(3) 200 rem, total dose.

SOLUTION:

(1) Enter Figure 2 at 1,900 r/hr (Dose Rate Normalized to H+1) and go vertically upward to the 2 hour (single exposure) curve, then horizontally to the left margin and read 34 1/2 (Time of Entry - Hours After Detonation). This is 31 1/2 hours after the peaked dose rate of 500 r/hr was determined at H+3.

(2) Enter Figure 3 at 1,900 r/hr (Dose Rate Normalized to H+1) and intersect the 2 hour (single exposure) curve at 18 1/2 hours (Time of Entry). This is 15 1/2 hours after the peaked dose rate was determined.

(3) Enter Figure 4 at 1,900 r/hr normalized dose rate and intersect the 2 hour curve at 10 hours after detonation. This is 7 hours after the peaked dose rate was determined.

d. Using the same reference dose rate as that used in example "c" above (1,900 r/hr) determine the earliest time a worker might enter the contaminated area for a single 8-hour exposure so as to receive a total dose not to exceed:

(1) 50 rem;

(2) 100 rem;

(3) 200 rem.

SOLUTION:

(1) Enter Figure 2 at 1,900 r/hr normalized dose rate and intersect the 8-hour (single exposure) curve at 111 1/2 hours after detonation. This is 108 1/2 hours after the peaked dose rate of 500 r/hr was determined.

(2) Enter Figure 3 at 1,900 r/hr normalized dose rate and read 61 1/2 hours after detonation (58 1/2 hours after peaked dose rate).

(3) Enter Figure 4 at 1,900 r/hr normalized dose rate and read 32 1/2 hours after detonation (29 1/2 hours after peaked dose rate).

e. Using the same reference dose rate as that used in examples "c" and "d" above (1,900 r/hr) determine the earliest time after detonation a worker might enter the contaminated area in order to work the maximum number of consecutive daily two-hour shifts so as to receive a total dose not to exceed:

(1) 50 rem;

(2) 100 rem;

(3) 200 rem.

SOLUTION:

(1) Enter Figure 5 at 1,900 r/hr normalized dose rate and intersect the 2 hour/day shift curve at 100 hours after detonation. (Time of Entry for 1st Shift). This is 97 hours after the peaked dose rate of 500 r/hr was determined. Note also that 50 rem will have been accumulated during the 11th shift.

(2) Enter Figure 6 at 1,900 r/hr normalized dose rate and read 37 hours after detonation (34 hours after peaked dose rate). The 100 rem will have been accumulated during the 7th shift.

(3) Enter Figure 7 at 1,900 r/hr normalized dose rate and read 13 1/2 hours after detonation (10 1/2 hours after peaked dose rate). The 200 rem will have been accumulated during the 4th shift.

f. By the use of Figure 8, determine the dose one would receive if he enters the contaminated area immediately after fallout has peaked (H+3 in examples b through e) and remains for:

(1) 15 minutes;

(2) 30 minutes;

(3) 1 hour.

SOLUTION:

(1) Enter Figure 8 at 3 hours (Time After Explosion) on left side and intersect the curve at 6.15 (ratio of Accumulated Total Dose to Unit-Time Reference Dose Rate). It is necessary to enter Figure 8 the second time, i.e., at 3.25 hours (Time after Explosion) and intersect the curve at 6.212 (ratio of Accumulated Total Dose to Unit-Time Reference Dose Rate). The meaning of these two ratios is as follows:

$$6.15 = \frac{\text{Accumulated Total Dose (r)}}{\text{Unit-Time Reference Dose Rate (r/hr)}} \text{ at H+3.}$$

$$6.212 = \frac{\text{Accumulated Total Dose (r)}}{\text{Unit-Time Reference Dose Rate (r/hr)}} \text{ at H+3.25 (3 hrs 15 min after burst).}$$

and (6.212-6.15) = Accumulated Total Dose at H+3.25 - Accumulated Total Dose at H+3 divided by Unit-Time Reference Dose Rate.

$$\text{or} \quad .062 = \frac{\text{Dose Accumulated in 15 min}}{\text{Unit-Time Reference Dose Rate}} \quad \text{or}$$

Dose Accumulated in 15 min = .062 x Unit-Time Reference Dose Rate.

Since the Unit-Time Reference Dose Rate found in example "b" was 1,900 r/hr, our answer becomes .062 x 1,900 = 118 rem (Ans.).

This 15-minute dose of 118 rem should not be surprising, for the dose rate at the time of entry (H+3) was 500 r/hr.

(2) Enter Figure 8 at 3.50 hours (Time after Explosion) and intersect the curve at 6.27. Subtracting the ratio 6.15 found above from 6.27 we have

$$.12 = \frac{\text{Dose Accumulated in 30 minutes}}{\text{Unit-Time Reference Dose Rate}}$$

or Dose Accumulated in 30 minutes (from H+3 to H+3.5) = .12 x 1900 = 228 rem.

(3) Enter Figure 8 at 4 hours (Time After Explosion) and intersect the curve at 6.37. Subtracting the ratio 6.15 found above from 6.37 we have

$$.22 = \frac{\text{Dose Accumulated in 1 Hour}}{\text{Unit-Time Reference Dose Rate}}$$

or Dose Accumulated in 1 hour (From H+3 to H+4) = .22 x 1900 = 413 rem.

g. Assume that personnel remain in fallout shelters for a 24-hour period after fallout has peaked and then are exposed, find the total dose which would be received for exposures of:

(1) 1 hour;

(2) 2 hours;

(3) [illegible] respectively.

SOLUTION:

(1) Enter Figure 8 at 27 hours (Time After Explosion) and read 7.49 ratio of Accumulated Total Dose to Unit-Time Reference Dose Rate. Read a second ratio of 7.51 at 28 hours. Subtracting 7.49 from 7.51 we get

$$.02 = \frac{\text{Dose Accumulated in 1 Hour}}{\text{Unit-Time Reference Dose Rate}}$$

or Dose Accumulated in 1 hr (From H+27 to H+28) = .02 x 1900 = 38 rem.

(2) Enter Figure 8 at 29 hours (Time After Explosion) and read 7.53. Subtracting 7.49 from 7.53 we get

$$.04 = \frac{\text{Dose Accumulated in 2 hours}}{\text{Unit-Time Reference Dose Rate}} \text{ or}$$

Dose Accumulated in 2 hours (From H+27 to H+29) = .04x 1900 = 76 rem.

(3) Enter Figure 8 at 30 hours (Time After Explosion) and read 7.55. Subtracting 7.49 from 7.55 we get

$$.06 = \frac{\text{Dose Accumulated in 3 Hours}}{\text{Unit-Time Reference Dose Rate}} \text{ or}$$

Dose Accumulated in 3 hrs (From H+27 to H+30) = .06 x 1900 = 114 rem.

h. Assume an exposure period to begin at H+11 hours (8 hours after fallout has peaked). Determine the duration of exposure necessary to accumulate 100 rem. The solution of this problem is the reverse of those just preceding.

SOLUTION

The problem is to find "X," the number of hours exposure in the fallout area, beginning at H+11, necessary to accumulate 100 rem.

1st Step

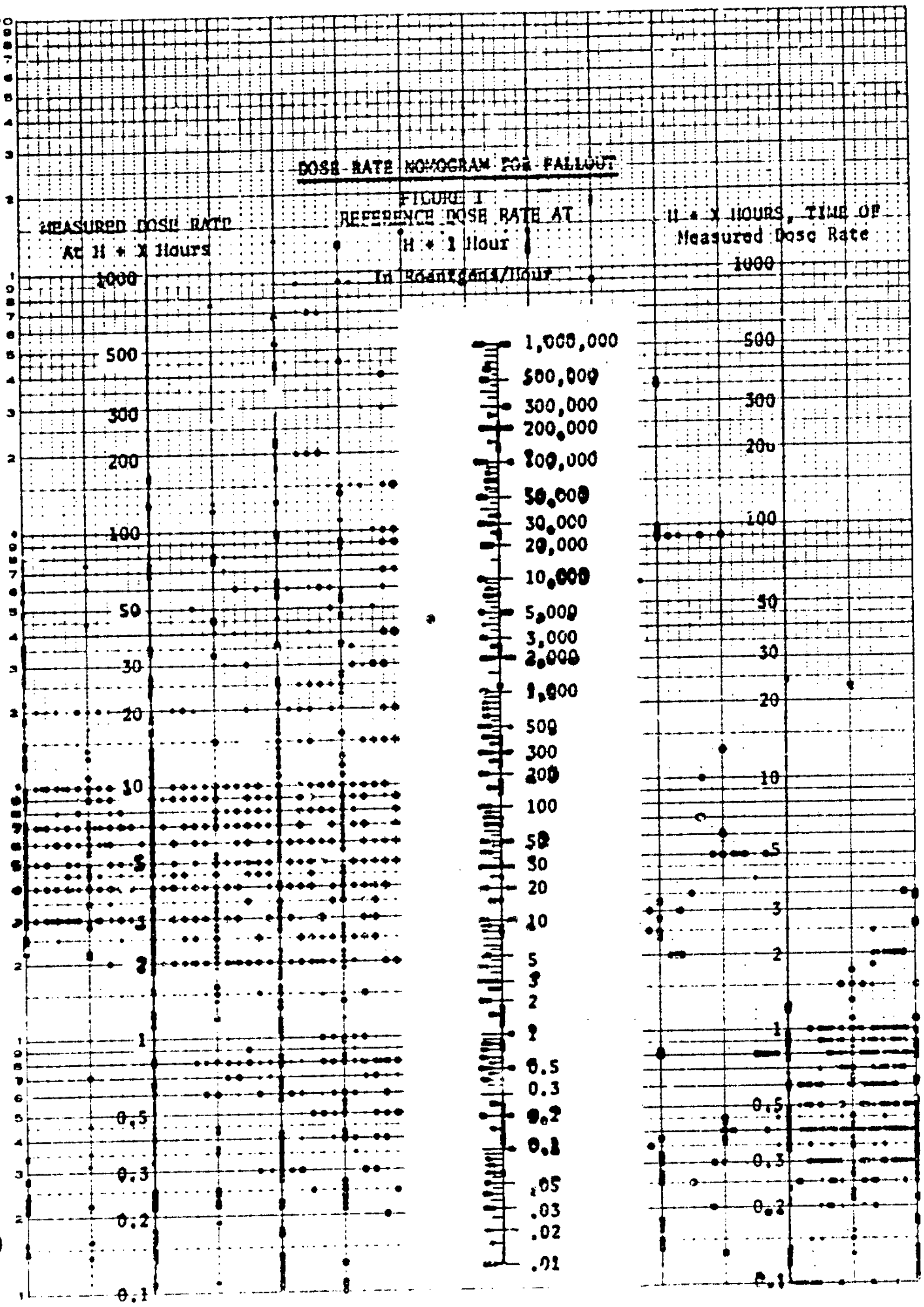
$$\frac{\text{Dose Accumulated in X Hours}}{\text{Unit-Time Reference Dose Rate}} = \frac{100 \text{ rem}}{1900 \text{ r/hr}} = .0526.$$

2nd Step

Find the ratio of Accumulated Dose Rate to the Unit-Time Reference Dose Rate at H+11. Enter Figure 8 at 11 hours (Time After Explosion) and read a ratio of 7.02.

3rd Step

Enter Figure 8 from the bottom at 7.073 and intersect the curve at 12 hours (Time After Explosion). Since 11 + X = 12, X=12-11=1 hour, the duration of exposure to accumulate 100 rem beginning at H+11. Ans.


DOSE RATE NOMOGRAM FOR FALLOUT
FIGURE I
MEASURED DOSE RATE
At H + X Hours
REFERENCE DOSE RATE AT
H + 1 Hour
In Roentgens/Hour
H + X HOURS, TIME OF
Measured Dose Rate
1000
500
300
200
100
50
30
20
10
5
3
2
1
0.5
0.3
0.2
0.1
1,000,000
500,000
300,000
200,000
100,000
50,000
30,000
20,000
10,000
5,000
3,000
2,000
1,000
500
300
200
100
50
30
20
10
5
3
2
1
0.5
0.3
0.2
0.1
.05
.03
.02
.01
1000
500
300
200
100
50
30
20
10
5
3
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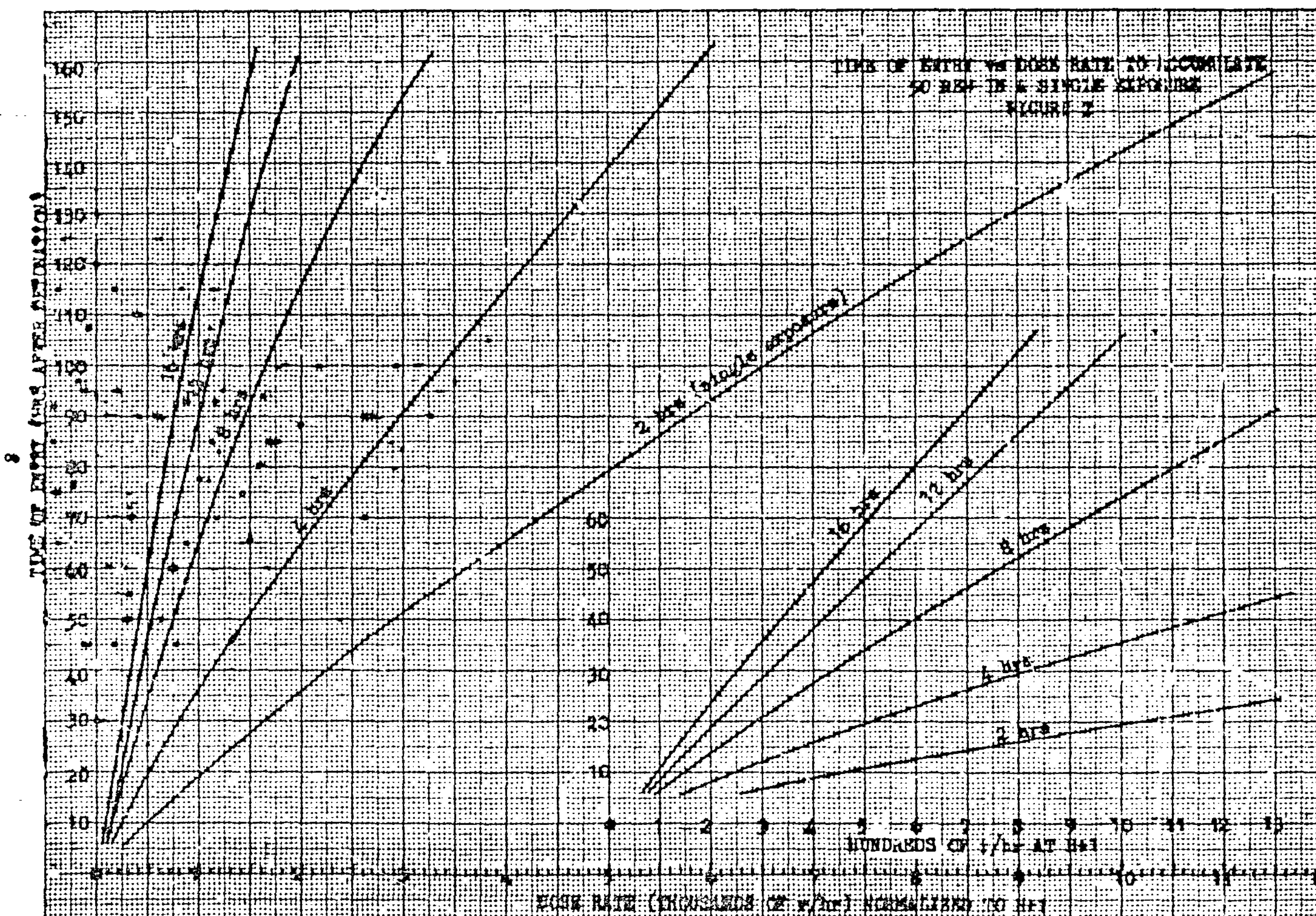
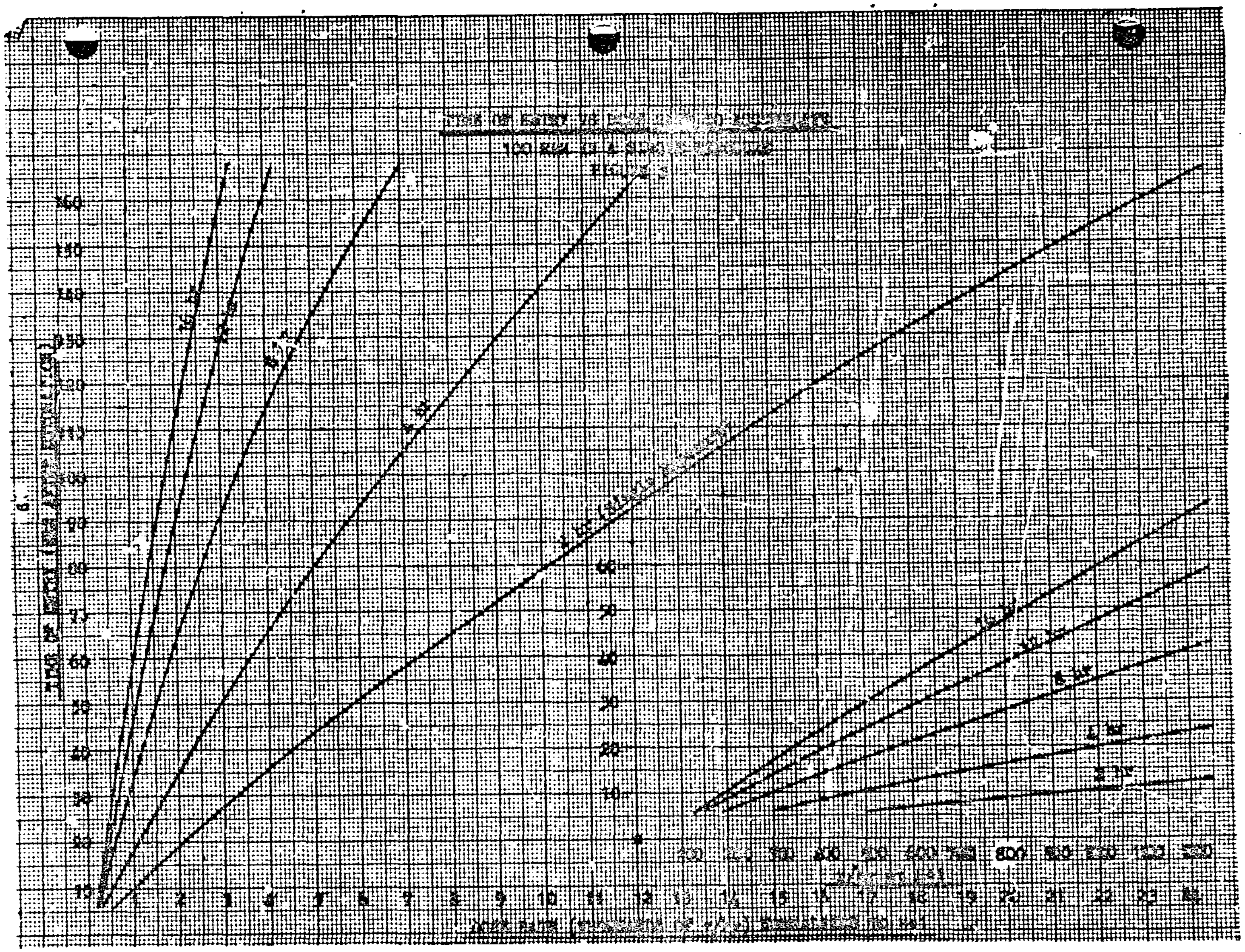
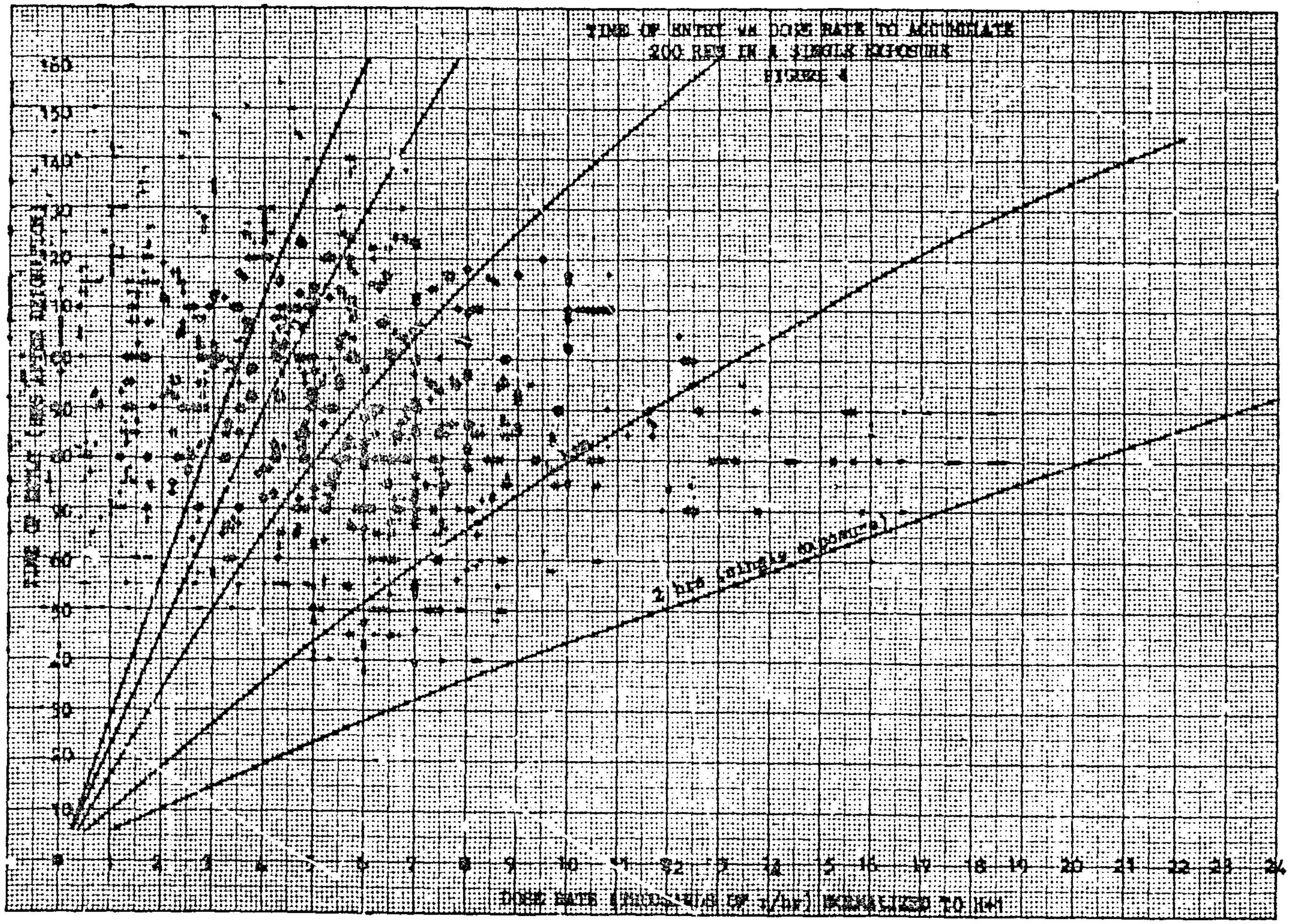
0.3
0.2
0.1



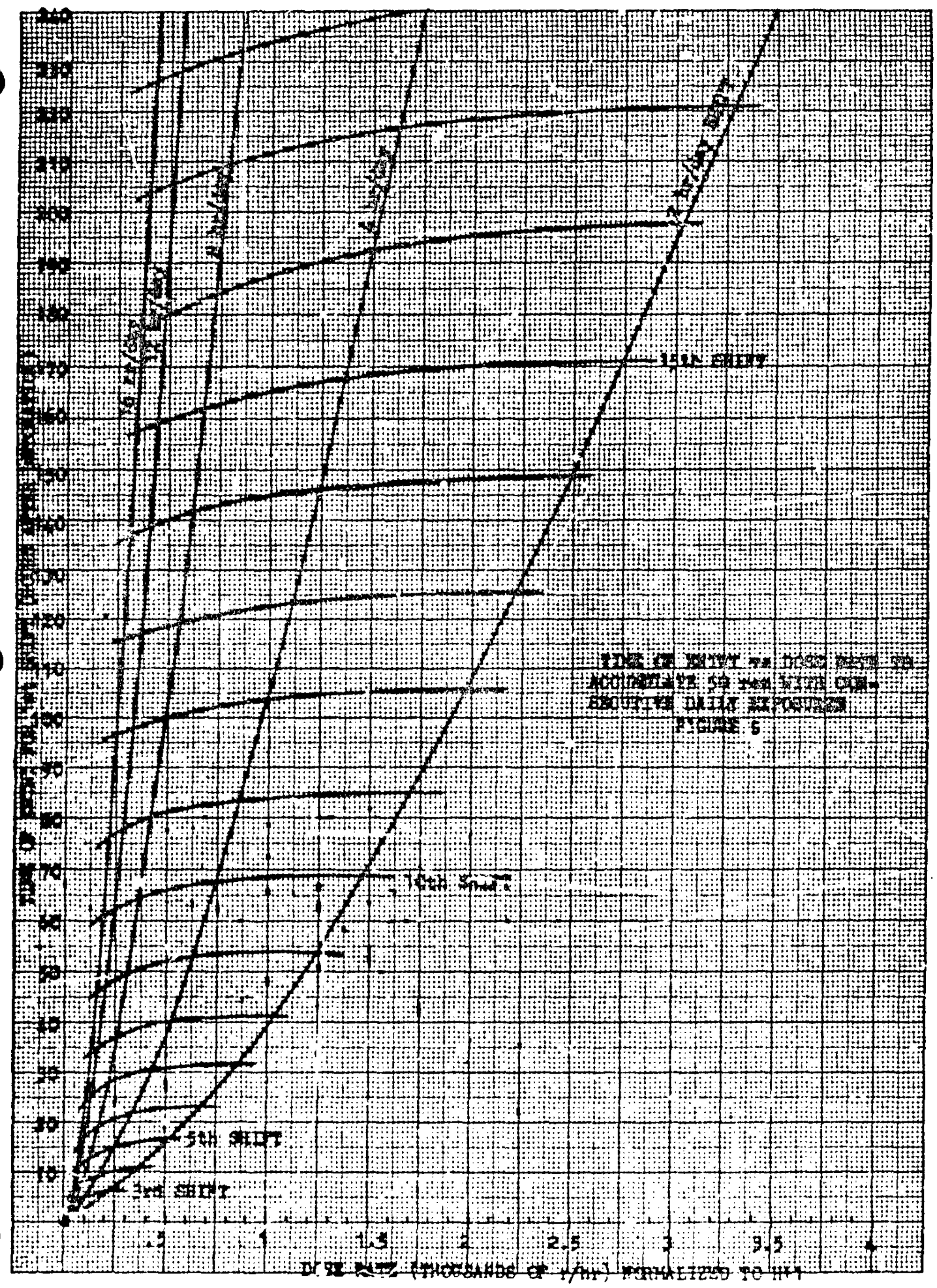

TIME OF ENTRY vs DOSE RATE TO ACCUMULATE
50 REM IN A SINGLE EXPOSURE
FIGURE 2



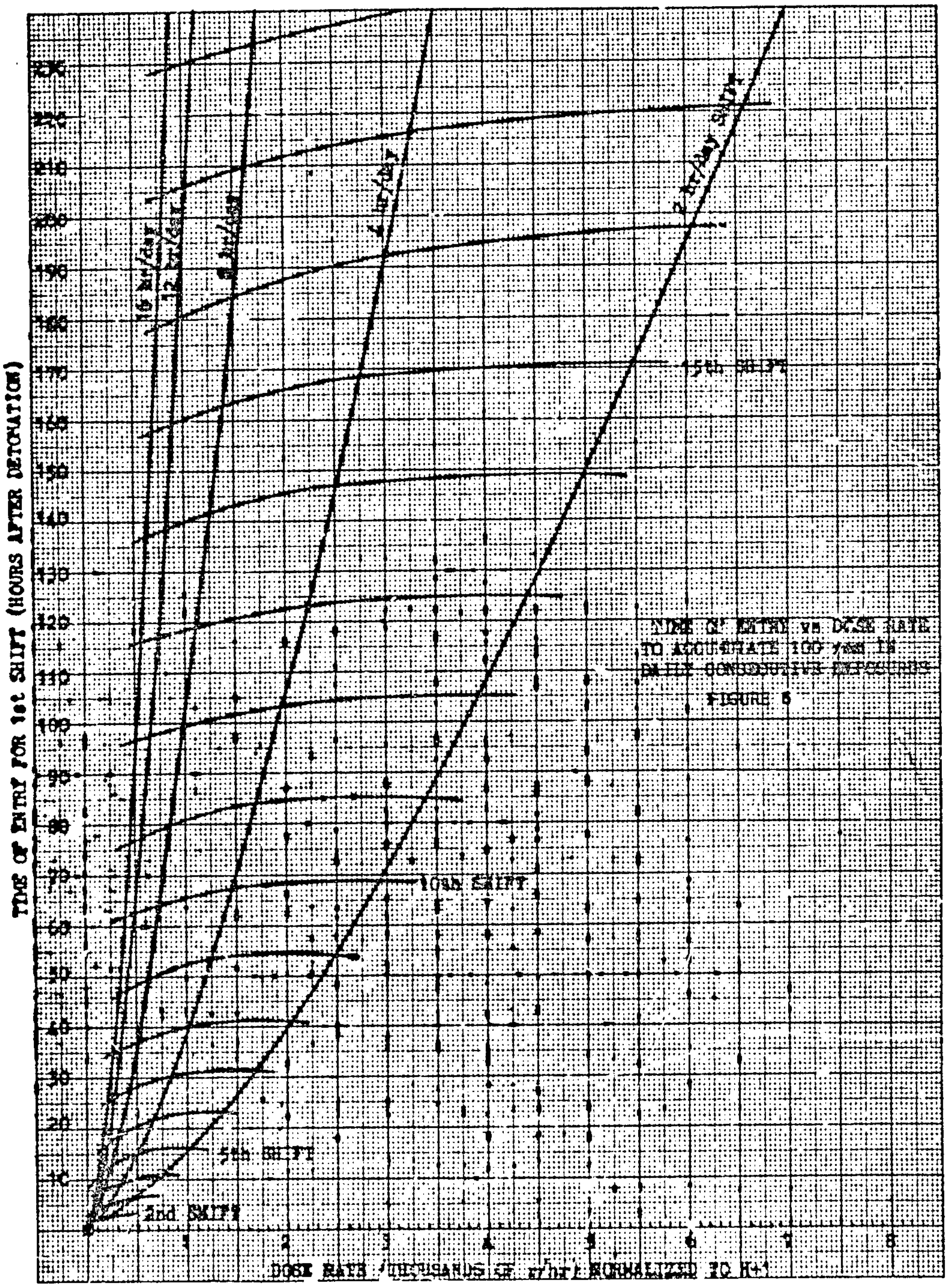
160
150
140
130
100
90
80
70
60
50
40
30
20
10
60
50
40
30
20
10
100 200 300 400 500 600 700 800 900 1000 1100 1200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24




TIME OF ENTRY VS DOSE RATE TO ACCUMULATE
200 REM IN A SINGLE EXPOSURE
FIGURE 4

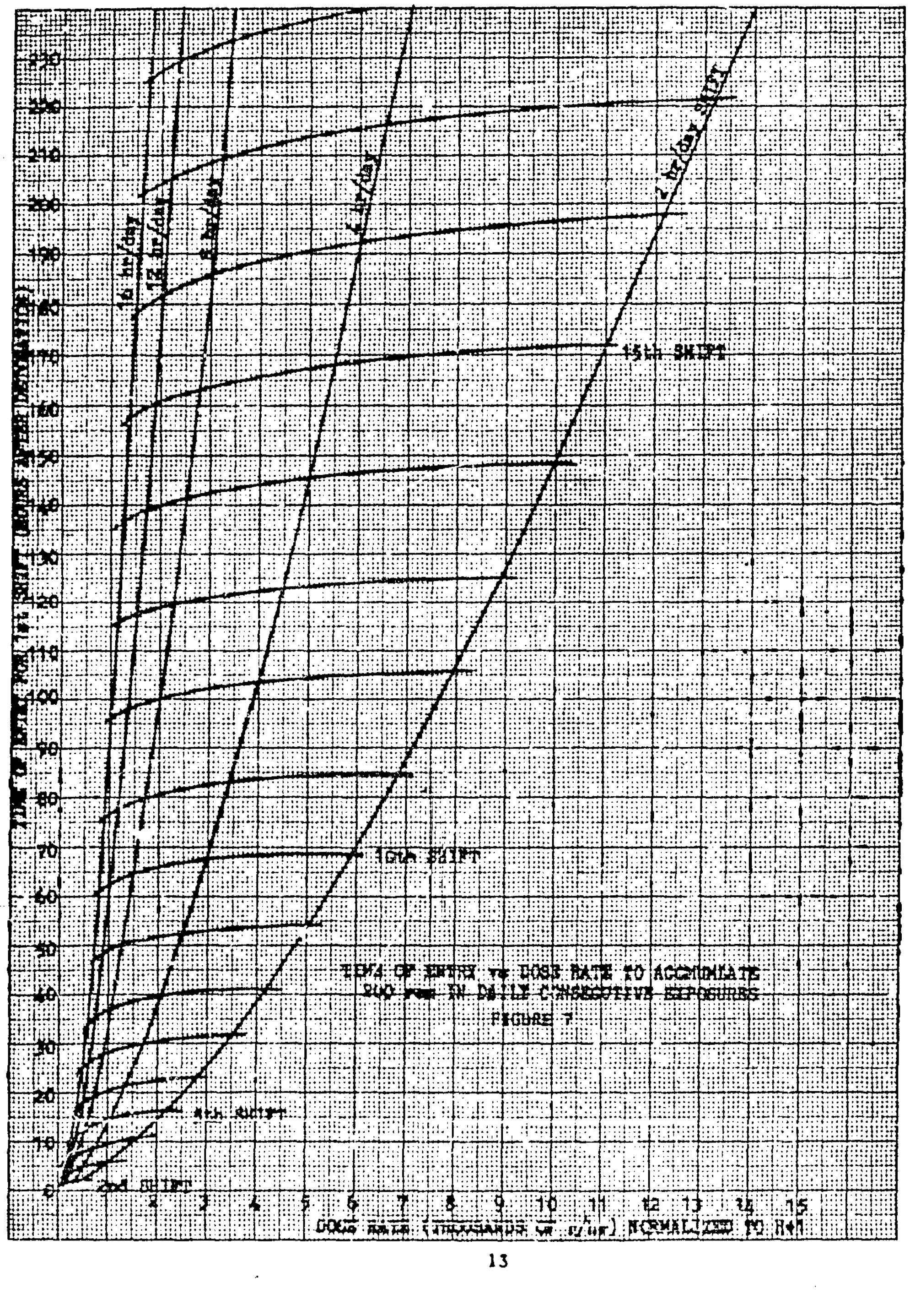



TIME OF ENTRY vs DOSE RATE TO ACCUMULATE 50 rem WITH CON-SECUTIVE DAILY EXPOSURES
FIGURE 6



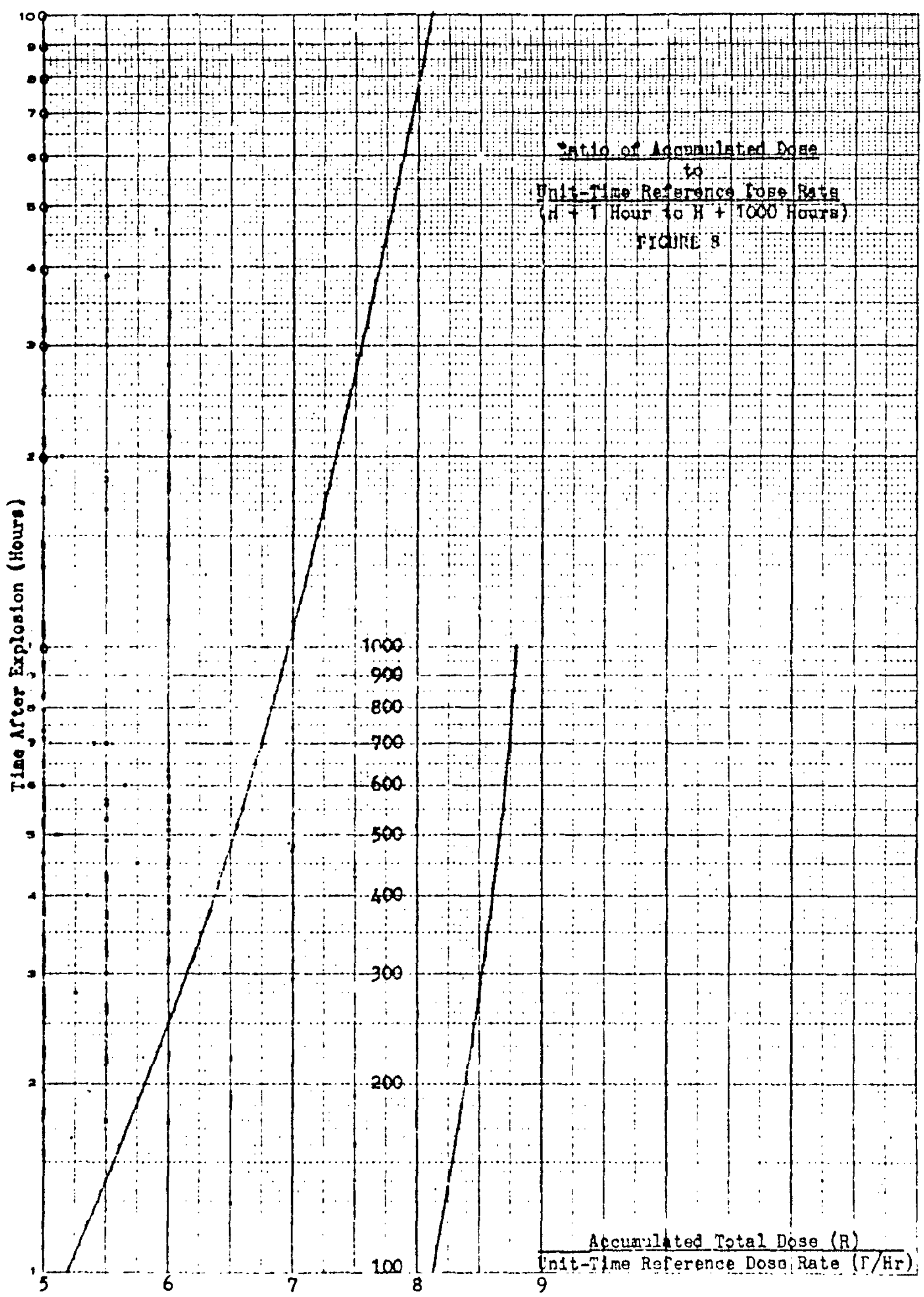

TIME OF ENTRY vs DOSE RATE TO ACCUMULATE 100 rem IN DAILY CONSECUTIVE EXPOSURES

FIGURE 5




TIME OF ENTRY vs DOSE RATE TO ACCUMULATE 200 rem IN DAILY CONSECUTIVE EXPOSURES

FIGURE 7



Ratio of Accumulated Dose
to
Unit-Time Reference Dose Rate
(H + 1 Hour to H + 1000 Hours)
FIGURE 8
Time After Explosion (Hours)
Accumulated Total Dose (R)
Unit-Time Reference Dose Rate (r/Hr)
1000
900
800
700
600
500
400
300
200
100
5
6
7
8
9

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